Survey and Alignment update from the Diamond Light Source

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Diamond is a 3GeV, 3rd Generation Synchrotron Light Source in the final stages of construction as part of the Harwell Science and Innovation Campus, Chilton, Oxfordshire. Included in the paper is a current status report for the facility as it approaches operation with an initial 7 phase 1 beamlines in January 2007. Survey and alignment techniques employed during the construction of the accelerators and beamlines is the main subject matter covering areas such as pre-alignment activities, installation alignment techniques and survey network performance. Instrument selection and operation is also covered reporting on both hardware and software systems that have been utilised.

1. PROGRESS OVERVIEW

Construction of the Diamond light source commenced in December 2003 with the pouring of the first section of storage ring floor slab. By the end of May the majority of the storage ring walls had been cast with the exception of a small area providing access to the central courtyard. At this stage both the linac and booster vaults were complete.

Figure 1: The Diamond site, July 2006

The linac installation completed at the beginning of August 2005 with first beam from the gun at the end of the month. The design parameter of 100 MeV injection energy was achieved on 7th September following which, beam commissioning continued until mid October when all design parameters where met, well within specification in both single and multi-bunch modes of operation [1].

Booster commissioning started in December 2005 with dc operation at 100MeV. An initial problem with the septum polarity was soon rectified following which the beam was successfully circulated through a complete turn, without correctors, on the night of 21st December. Following minor adjustments the beam circulated for over 1000 turns with sextupoles and RF off and on 10th March the first acceleration to 700 MeV was obtained. As soon as temporary cooling water was available 3GeV testing commenced and the first acceleration to 3 GeV was attained on 7th June [2].

The last of the 72 storage ring girders was installed on 13th March 2006, completing the installation of the 24-cell double bend achromatic lattice. Commissioning at 700 MeV started on the 3rd May with beam successfully delivered along the transfer line from the booster to the injection septum magnet. The following night a complete turn was achieved around the 561.6m circumference, without the sextupoles and RF cavity operating, followed by 4 and then 600 turns on subsequent nights. By the 19th May, with the sextupoles on, 2000 turns had been achieved and with RF on the following night, the beam survived for 100,000 turns i.e. 200 ms between injections from the booster [3]. Phase 1 commissioning at 700 MeV was deemed a success however, a lack of cooling water meant that progression to 3 GeV commissioning was not possible. To minimize delays it was decided to bring forward the installation of the 7 phase 1 insertion devices. These were installed during a 3 month shutdown completed at the beginning of September.

On completion of the shutdown, with cooling water available, 3 GeV commissioning commenced on the evening of the 4th September. By the end of the night 6 turns had been achieved with RF off, nominal settings on injection kickers, quadrupoles and dipoles were used and no corrector magnets were required, and with RF operating 5 days later the beam was stored at 10 mA.

2. SURVEY NETWORK

The Diamond accelerators are installed in 3 independent vaults housing the linac, booster and storage ring respectively. Each vault contains a survey network consisting of wall mounted survey monuments plus wall and floor mounted target nests. The survey monument target interface is also used as a force-centred instrument station for theodolites and total stations. This feature allows both measured and resected values for the monuments to be used within the network. The design of these networks was presented at the 2004 IWAA and included survey results for the booster vault network [4]. Fig. 2 identifies the observational geometry for the 3 networks including link shots joining them together.

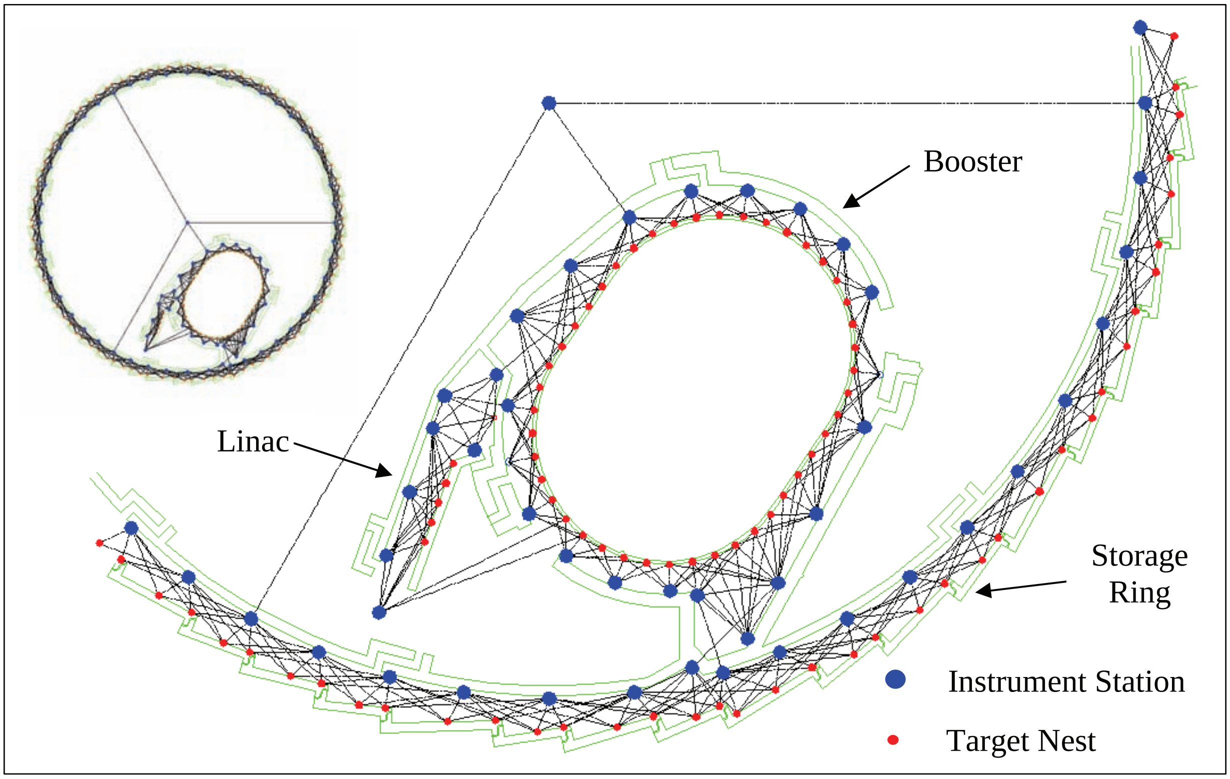

Figure 2: Survey geometry for the storage ring, booster and linac vaults

2.1. Storage Ring Tunnel Network

The storage ring tunnel network was installed and measured in October 2004. Consisting of 48 instruments stations and 96 wall nests, a total of 384 observations completed the survey. Two Leica TDA-5005 total stations were used for the measurements which were then post processed using a free network least squares adjustment. This network defined the planimetric control for the subsequent installation tasks. Figure 3 details the error ellipses representing the calculated uncertainty for each point within the network.

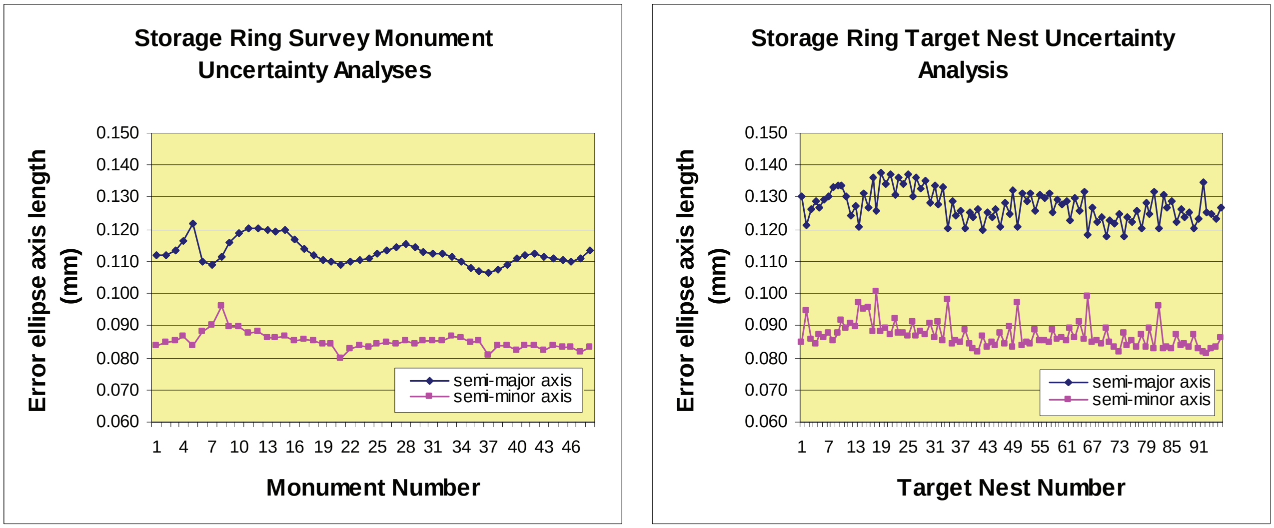

Figure 3: Storage ring survey network planimetric uncertainty

The altimetric control is provided by 48 floor mounted target nests positioned on each ID straight and at the centre of each cell. A 2-way levelling run was first carried out in October 2004 and subsequently repeated approximately every 3 months, time permitting. Fig 4 details the relative vertical movement of these target nests between surveys. The average misclosure for all the levelling runs was 0.2mm.

Following an initial global settlement of 2.5mm during civil construction the average global settlement has reduced to a value of -0.227 mm over this 19 month period. This was measured with respect to a benchmark on the central survey monument which is set on top of a 12m deep pile.

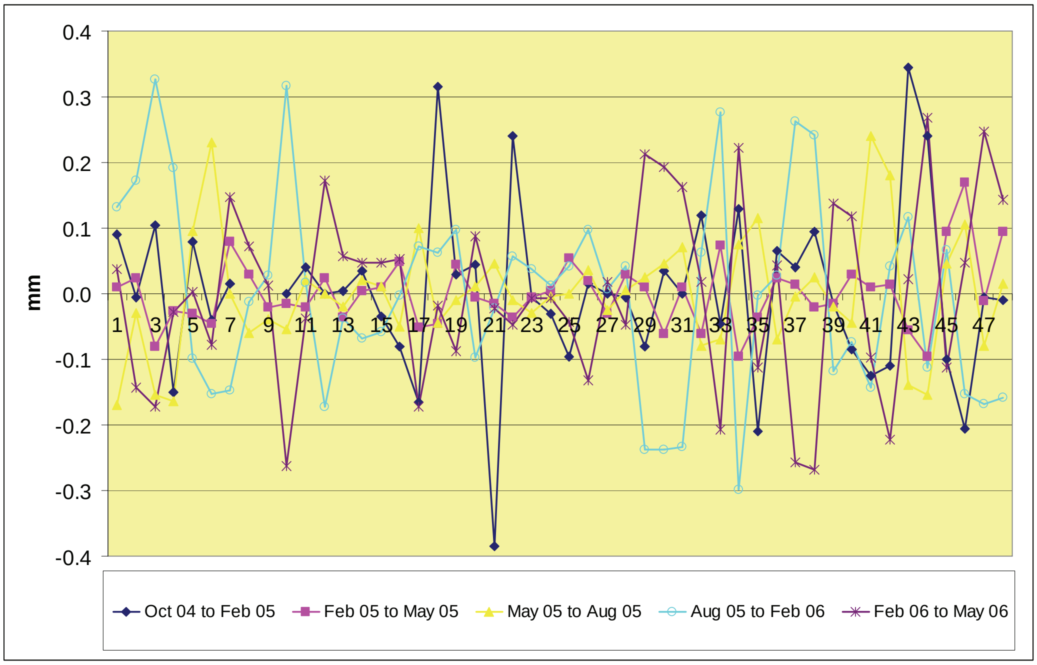

Figure 4: Rise/Fall of adjacent storage ring floor nests over time.

3. MACHINE ALIGNMENT

3.1. Linac

During the installation of the linac gun, accelerating structures and linac to booster (LTB) transfer line, the linac vault survey network was enhanced to provide a more dense control for the alignment tasks and to provide 3-D co-ordinate data for all points within the network. Using a Faro laser tracker running Spatial Analyzer (SA) software, multi-station observations were taken to both the additional target nests and the existing survey network within the vault. All measurements were taken in two-face mode using interferometer distance measurements.

With all measurements taken, SA's Unified Spatial Metrology Network (USMN) function was used to best fit and then solve the network. During this process statistical analysis tools flagged up outliers from the residual fit data that the user had the opportunity to isolate and then re-solve the network.

At any stage throughout the operation the user could view the fit data of each instrument within network. This was represented as the standard deviation of the fit residuals for each component of the measurement; horizontal angle, vertical angle and distance. This extremely useful function allows the user to validate instrument performance with respect to the specific measurement geometry and environmental conditions applicable at the time.

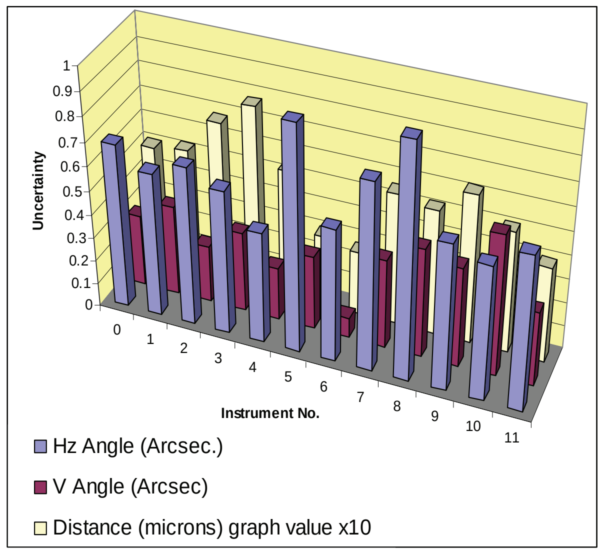

Figure 5: Instrument uncertainty values

The default uncertainty settings for laser trackers within SA are 1.3 arc seconds for horizontal & vertical angles and 15 microns for distance. Figure 5 details the uncertainty values computed for each of the instruments within the network. All values were well within the default generic laser tracker parameters.

The process as described above was very quick taking less than a minute to perform by an experienced user. As the default uncertainty values for the instrument had proven to be rather pessimistic the instrument uncertainty values were reset to represent the average of the instruments within the job and then the network was re-solved. A re-check of the instrument fit data confirmed the settings to be repeatable.

The final operation within the USMN function was to compute the uncertainty fields for all of the measured points within the network. This automated process only requires the user to define the number of iterations required and a time limit for the process to complete. For this network the analysis completed in 4 1/2 minutes on a Pentium 4, 3 GHz PC with 2 GB of RAM. The average error cloud magnitude was computed to be 29 µm and the maximum was 65 µm. Figure 6 identifies the network geometry with error clouds representing the uncertainty fields for each point.

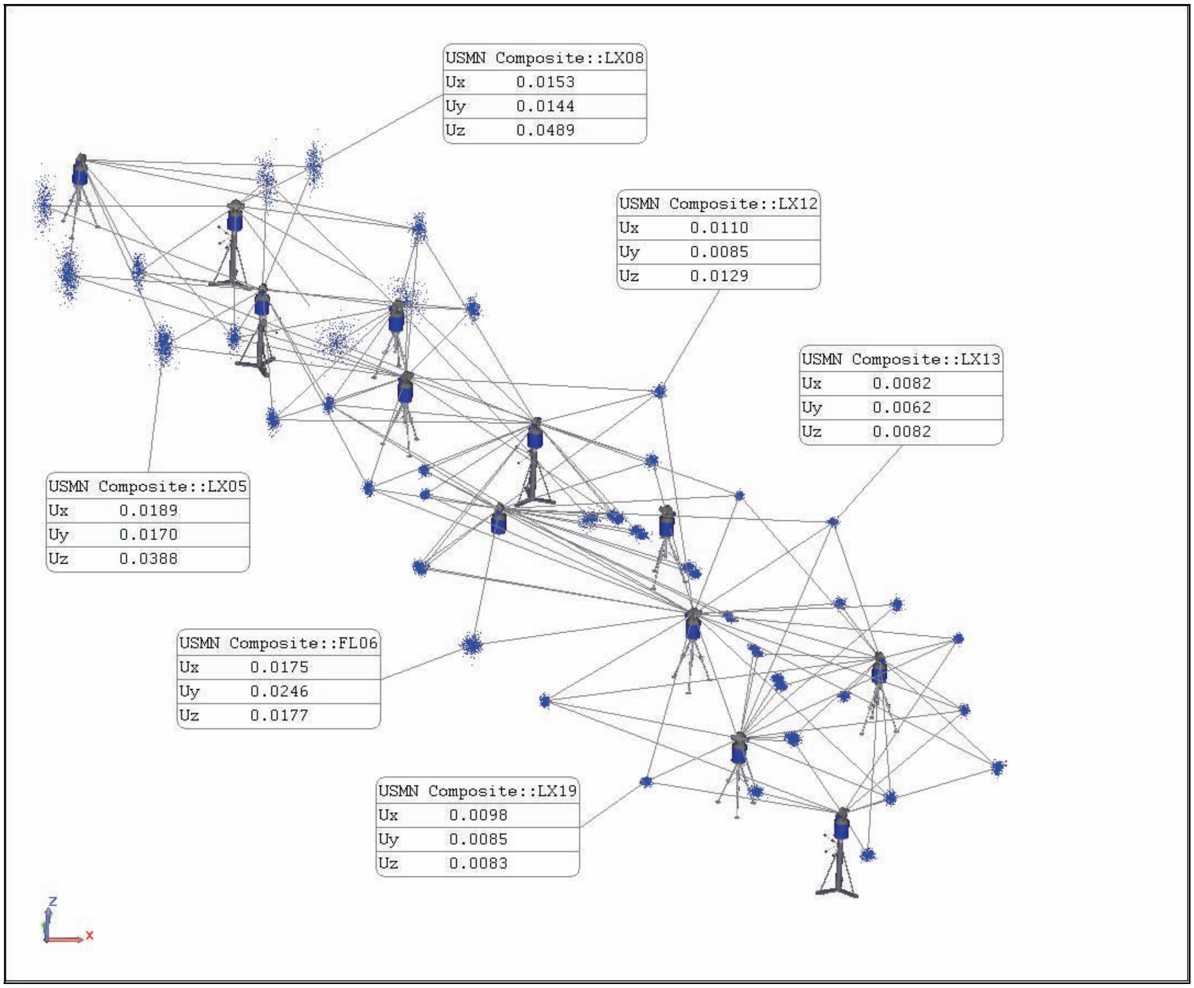

Figure 6: Linac vault network geometry including error cloud uncertainty representation

The final operation was to best-fit the enhanced network to the original control network to bring it into the site co-ordinate system. As the original network combined altimetric data from level measurements and planimetric data from total station measurements, the fit had to be weighted to reflect this.

Figure 7 details the input data selected for the best-fit transformation. All checked target points were used in the transformation however, the greyed out co-ordinate values indicate where a component of the co-ordinate has been excluded from the fit. Fit residuals for all target points within the network are displayed.

With the 3D network in place the subsequent alignment tasks were relatively straight forward using fiducials on the components to align them to the network with the laser tracker.

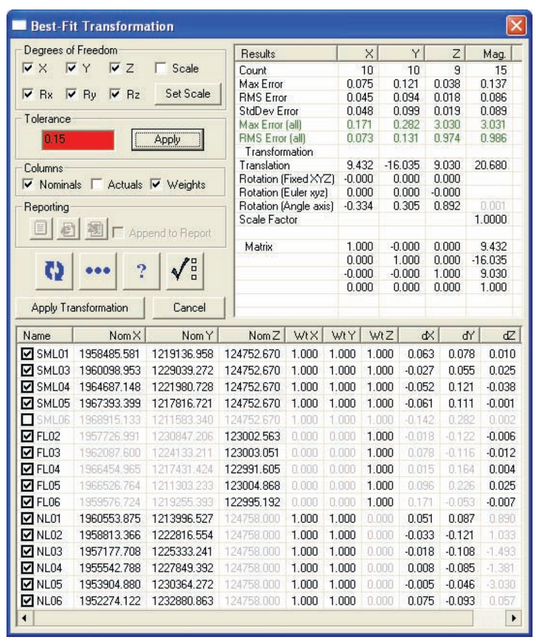

Figure 7: USMN best-fit

The LTB magnets were fiducialised by the supplier therefore these could be installed directly upon receipt. The linac components however required pre-aligning before their final position could be defined. Typically external features on the assemblies were utilised to establish a local co-ordinate frame on the assembly following which the co-ordinates of fiducial targets were valued. A corresponding co-ordinate frame was created within the site co-ordinate system defining the nominal position and orientation of the assembly. A frame to frame transformation was then carried out to determine the installation co-ordinates for the assembly on site.

This process was used for all of the linac components and proved very straight forward however, the accelerating structures required an additional operation before the co-ordinate frame could be established. Because of the flexible nature of the accelerating sections, an optimum straightness had to be obtained along the beam axis. A laser tracker was used to measure a series of peripheral points around each of the 2 sections adjacent to the support positions along their length, figure 8. A series of best fit circles were then constructed and the centre points computed. By fitting a best fit line through the circle centres the straightness was calculated and the deviation at the supports determined.

Figure 8: Linac accelerating section survey

Using Dial gauges mounted on the top and side of the accelerating section local to the supports, each location was adjusted to achieve the required straightness. On completion, a second survey was carried out and the best fit line used to define the nominal beam axis for installation.

3.2. Booster

The 44 booster girder assemblies were supplied as a turnkey contract with all pre-alignment tasks being carried out by the supplier. Each girder was supplied with target mounting features and a horizontal reference surface, which together defined the girders position and orientation within the vault. Manual adjustment was provided with longitudinal and transverse turnbuckles for planimetric adjustment and 3 adjustable support legs for vertical adjustment.

The installation procedure was to align every other girder with respect to the survey network then systematically insert the remaining girders, survey into position then make the vacuum connections. It was decided to use a laser tracker for this purpose as its dynamic measurement capability allowed real time feedback of measured data during the alignment task.

Typically laser trackers are not referenced to gravity therefore a 3D control network is required to define their position and orientation within the network. As the vertical component of the booster network had been decoupled from the x,y component, complete 3D data for any of the points within the network was not available. Of course a 3D network could have been created as described for the linac but this would have been time consuming and so was to be avoided if possible.

The Faro laser tracker is fitted with an internal gyro as standard, which allows it to measure its orientation with respect to gravity to within 2 arc seconds. This functionality allowed the tracker to book into the planimetric co-ordinates from the total station survey and the altimetric values from the level survey whilst maintaining a co-ordinate frame level to gravity.

The first 22 girders were quickly aligned to the survey network as described above however, when attempting to fit the 23rd girder between its neighbours a problem was discovered. With the girder aligned to the network via its fiducial targets a misalignment of its vacuum vessel with respect to that of its neighbours was evident. It was not possible to make the vacuum connections and maintain the desired alignment; inspection of a sample of the other girders identified this to be a common problem. An unforeseen pre-alignment task was therefore required before the vacuum connections could be made.

Figure 9: Booster girder alignment

Each girder was inspected using a laser tracker to determine the vertical and horizontal offset that needed to be applied to the vacuum vessel flanges at each end of the girder. When the tracker moved onto the next girder a mechanical technician set up dial gauges on the flanges then adjusted the vacuum chamber to the desired location. A final inspection with the tracker was carried out to ensure compliance to specification then the girder was installed, Figure 9.

On completion of the assembly a full global survey was carried out, best fitted against design nominal. A final adjustment was then carried out prior to first beam being injected in December 2005; no further adjustment has been required to date

3.3. Storage Ring

Diamond's storage ring consists of 72 girders, 3 per cell, which come in 2 lengths ~ 5.9m and 4.3m, the longer girders accommodating the dipole magnets [5]. Between the cells are 24 straight sections, which come in 5m and 8m lengths. At full capacity; insertion devices can be installed in 22 of the straights with the remainder being utilised for Beam Injection and RF Cavities.

3.3.1. Girder Assembly

All of the SR girder assemblies were built in a dedicated facility on site. Each girder's top surface was supplied to the site following accurate machining to provide mechanical alignment features for the main components of the assembly i.e. the magnets and vacuum vessels. The machining process for the alignment features was qualified using an autocollimator for straightness and a inclination sensor for flatness. Both parameters achieved the 20 µm specified design tolerance throughout the production run.

During prototype qualification the survey group provided an inspection service to the Engineering, Vacuum and Magnets groups to ensure that sub-contractor supplied components and assemblies met the required dimensional specifications.

The Faro laser tracker proved to be a very flexible and accurate piece of equipment for this application. Taking the measurement system to the workplace meant that in process assembly sequences could be quickly qualified utilizing the girder alignment system as the datum.

Figure 10 illustrates an example of a vacuum vessel survey. The laser tracker measures to a spherical retro-reflecting target therefore when measuring a surface a vector offset needs to be applied to compensate for the sphere radius.

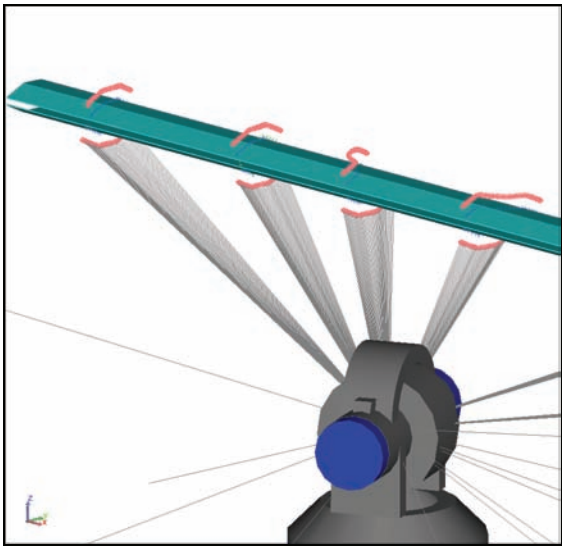

Figure 10: Inspection of vacuum vessel

To enable this operation and to provide nominal surface data to measure against, a CAD model of the component was imported into the SA software running the laser tracker. An alignment frame was created using measured points on the girder and this was then used to align the CAD model. With the CAD model alignment complete, measurements were taken of the vacuum vessel at key sections where it would pass through the magnets and where clearance was necessarily limited. The final operation was to query the measured point position with respect to the CAD model. The offset vector direction for the sphere radius is defined perpendicular to the closest point on the selected surface. The measured point is then projected along this line by a magnitude equal to the radius of the spherical target. A vector plot was then produced for each section; defining the deviation from design nominal, figure 11.

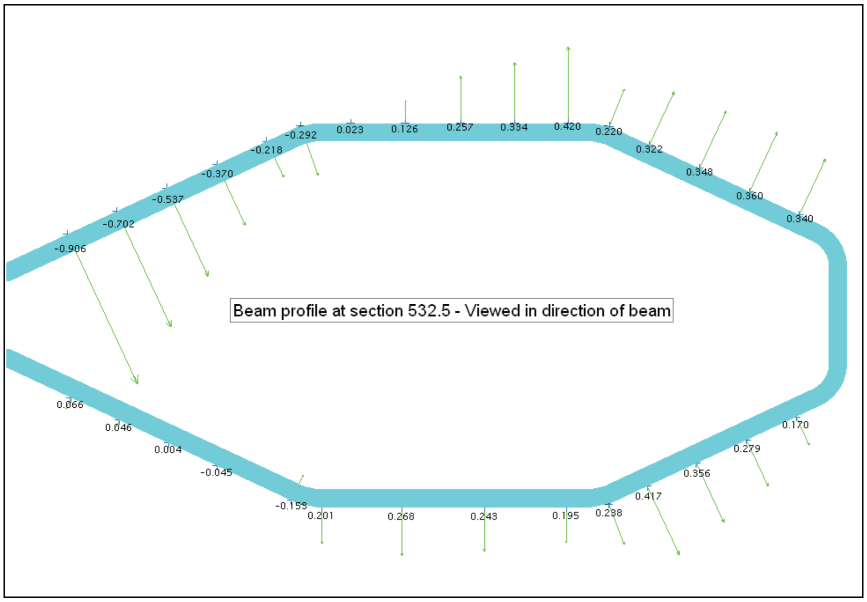

Figure 11: Example of a vacuum vessel survey report

Once the various manufacturing processes were accepted, the assembly production run commenced. The mechanical features on the girders aligned the components in all but the longitudinal position; this degree of freedom was controlled using a laser tracker.

The final task once each girder build was complete was to align a survey monument at each end of the girder co-linear with the nominal beam axis at a predetermined height above beam centre. The monuments, originally designed for CERN applications, provide a conical mount for targeting purposes and a force-centring interface for theodolites. Aligning the monuments as described allows a direct transfer of the beamline datum from the as-built storage ring position to the beamline hutches via a survey port in the ratchet wall.

Each survey monument was aligned using a laser tracker booked into the mechanical alignment features of the girder. A 3-station qualification survey was then conducted which included all magnet fiducial points as well as the aligned survey monuments. This survey identified a problem caused by temperature changes during the alignment process. If one survey monument was positioned in the morning and the second in the afternoon, the vertical displacement between them could be tens of microns when surveyed at completion. To alleviate the problem temperature corrections were applied at each alignment stage benchmarked against the nominal operating temperature of the storage ring. This solution proved to be successful when checked in the SR vault.

3.3.2. SR Girder Survey

As the girders were installed they were locally aligned to the survey network using a total station, digital level and inclination sensor. A relative alignment tolerance of +/- 0.5 mm was required at this stage to allow the girder vacuum connections to be made. Initial beam commissioning would be carried out without insertion devices therefore make-up vessels were installed on each of the ID straights to complete the vacuum chain.

On completion of the installation, a global survey was carried out to determine the as installed position and orientation of the girders. The survey was carried out in 3 operations namely a planimetric (x,y) survey using TDA-5005 total stations, altimetric (z) using Dini 12 digital levels and a roll survey on each of the girders using Nivel level 20 inclination sensors.

The planimetric survey consisted of 48 instrument stations measuring 144 survey monuments (2 per girder), each survey monument being measured from 5 instrument stations. A software program developed for Diamond by a work experience student during the summer of 2005 was utilised to automate the measurement process. Once the instrument was stationed and orientated on the first target, it was automatically driven to and measured a sequence of targets. Additional functionality allowed the instrument to switch face then repeat the measurements in the reverse order. Any number of user-defined measurements could be taken for each point and at the end of the run the closure error was displayed and recorded. Additionally the standard deviation and spread of the measurements was computed and available to the user on completion of the measurement sequence. A quick analysis of the data quality was then carried out prior to moving to the next station. If a bad measurement was discovered then this could be re-taken in one or both faces as required without the need to repeat the entire run. For this particular survey 3 measurements on each face were taken, the average being computed to be utilised in the least squares adjustment.

On average each station's measurements took 30 minutes to complete, introducing a 50% improvement in efficiency and significantly reducing operator fatigue.

The survey was carried out in less than ideal circumstances, installation work was still ongoing and a small number of sight lines were blocked. It was decided however to run the least squares adjustment with diminished observations and assess the results on completion.

The radial uncertainty of the network was well within the design specification of 0.1mm and the predicted longitudinal uncertainty of 0.16mm was only exceeded in a small number of positions, figure 12. The survey data was fine for this stage of the project and could be improved later.

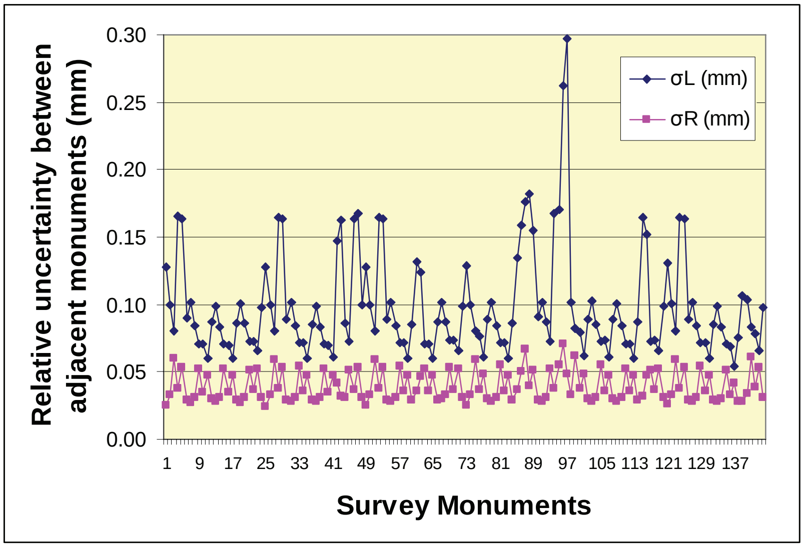

Figure. 12 SR Girder planimetric relative uncertainty

The altimetric survey utilised the same wall mounted survey monuments as used for the total stations to provide a stable platform for stationing the instrument. As these were all positioned at a common height, the instrument was by default at the correct height for measuring the elevation of the invar staff mounted on the SR monument. From each station a 2-way levelling run was carried out. The instrument was set to only accept an elevation where the SD of a series of measurements was within 0.02mm, once the run was completed the rise/fall of the outward and inward run were compared and only measurements that correlated to within 0.04mm were accepted. The average value was then used as the input to the adjustment process. Each rise/fall between adjacent monuments around the ring was measured from 2 independent stations. By combining the elevation and distance measurements from each station the collimation error of the instrument was calculated and an adjusted rise/fall applied [6]. Once all the adjusted values had been entered the closure error of the run was calculated and distributed. An instrument interface, written in house, was used to transfer the measured data directly into the processing spreadsheet compiled within Excel. For this particular levelling run the closure error computed to 0.1mm i.e. ~1.5µm per girder.

To measure the roll angle of each girder a Nivel level 20 inclination sensor was selected having a measurement resolution of 1µ radian. An interface plate was manufactured that spanned the 2 horizontal reference surfaces on top of the girder. To compensate for any parallelism issues with the plate the roll was measured twice with the assembly rotated through 180 decimal degrees between measurements. An in house developed instrument interface recorded the measurements and computed the adjusted roll angle.

With all 3 aspects of the survey completed the x,y,z co-ordinates of each girders survey monuments and each girders roll value were input into a processing spreadsheet to determine the input data for the girder mover system.

3.3.3. SR Girder Alignment

Each girder is provided with a remote alignment system allowing automated motion in 5 degrees of freedom. The girders rest on four motorised cam assembly blocks which form a “cone, groove and flat” kinematic mount, in which the groove is split with one face on either side of the girder, figure 13. The design for the Diamond storage ring girders has been developed from the solution adopted for the SLS, which in turn built on previous work on remote alignment at SLAC [7, 8].

Using a right-handed Cartesian coordinate system in which *x* points radially outwards, *y* is upwards and *z* follows the beam direction, the degrees of freedom controllable using the cams are:

- Sway, u (translation along *x* axis)
- Heave, v (translation along the *y* axis)
- Pitch, χ (rotation around *x* axis)
- Yaw, η (rotation around *y* axis)
- Roll, σ (rotation around *z* axis)

The surge of each girder (translation along *z* axis) is altered manually.

Figure 13: One of the 4 cam assemblies

Camshaft rotation angles are calculated using the equation [9] :

$$\phi = \psi_0 + \sigma \pm \cos^{-1}\left(\cos\psi_0 \frac{u - \sigma m_y + \eta m_z}{b} + \sin\psi_0 \frac{v + \sigma m_x - \chi m_z}{b} \right)$$

where *ø* is the camshaft rotation angle with respect to the *x* axis, ψ_0 is the angle between the *x* axis and a vector pointing from the cam centre to the girder contact point, *b* is the distance between the centre of the cam and the centre of the camshaft and the constants *m* are distances between the camshaft centres and the point of origin for the electron beam axis at the centre of the girder.

Following the storage ring survey all data was entered into a spreadsheet, which calculated the girders spatial position in terms of pitch, yaw, roll, heave, sway and surge. This provided the input data for the mover system however; at this stage of the project the system had not been fully commissioned. This meant that a full global alignment of the ring was not possible in the time available.

Analysis of the survey data indicated that the alignment was adequate for phase 1 commissioning at 700 MeV providing a priority section of 14 girders could be re-aligned. This area had seen a local distortion of the survey network when the storage ring walls had been completed. The largest girder movement required in this area was 1.2mm.

Prior to moving the girders, control points in the area were valued using a laser tracker. Post adjustment, these were used to book back into the co-ordinate system and qualify the new girder positions. Figure 14 shows the position and orientation of the 14 girders prior to adjustment and Figure 15 shows the same data after adjustment [10].

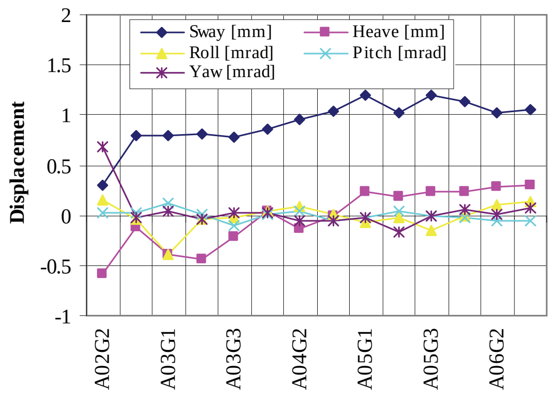

Figure 14: Post-construction survey results. Data shown for girders selected for priority realignment.

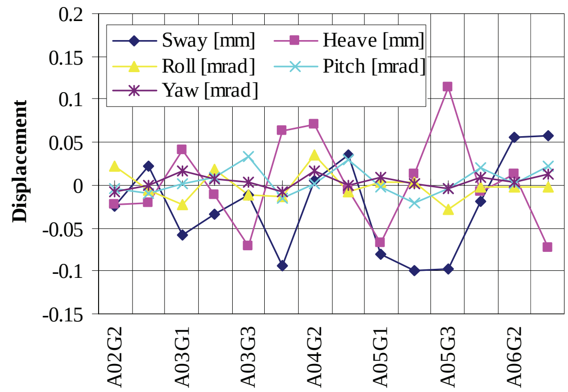

Figure 15: Survey results for selected girders following realignment using remote alignment system.

At the end of the August 2006 shutdown and immediately prior to the start of 3 GeV commissioning, the global storage ring survey was repeated. Figure 16 identifies the current adjustments required to bring the girders to their design nominal position. The most significant adjustment required relates to heave, the vertical position of the girders and is attributed to floor slab movement over the 4 Month period between surveys.

A re-alignment of the girders will occur at a convenient time within the commissioning schedule.

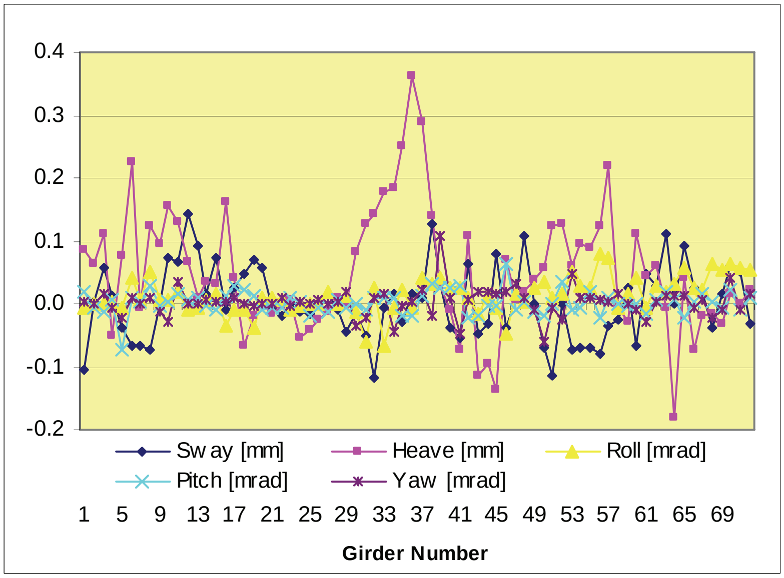

Figure 16: Girder Mover System Input Data

3.3.4. SR Primary Electron Beam Position Monitor (PEBPM) Alignment

The PEBPMs are mounted on their own stands at the entry and exit of each cell adjacent to the insertion devices. Their purpose is to measure the position of the electron beam and maintain a constant reference when using beam based alignment techniques. Each assembly is fitted with orthogonally mounted linear transducers which monitor local movements with respect to a carbon fibre reference pillar.

Each PEBPM assembly is fitted with a kinematic mount designed to receive a survey jig. A cone, vee and flat are provided to interface with 3 tooling balls mounted on the underside of the survey jig, figure 17. This solution avoids the need to install large survey monuments on each assembly.

On top of the jig are survey monuments positioned co-linear with the beam axis and at a fixed height above it, figure 18. A Nivel level 20 inclination sensor controls the roll for the assembly.

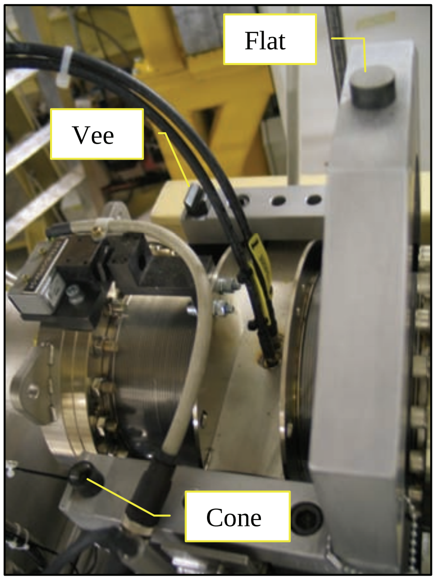

Figure 17: Survey jig mounting points

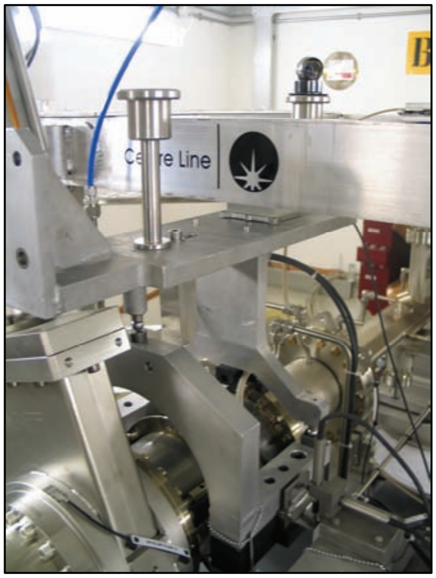

Figure 18: PEBPM Survey jig

The 48 PEBPMs were initially surveyed as a network in the same way as the SR girders. The diagnostics group were happy to work with offsets for elevation and lateral position within a range of +/- 0.5mm. Where this tolerance was exceeded a laser tracker was used to align the assembly to within specification after booking into the girder survey network.

3.3.5. Front End Alignment

Each of the front end components were supplied with survey monuments positioned at either end at a pre-defined height above beam centre. Initially it was planned to use a theodolite and level to align the front end however, an oversight in manufacture resulted in the line of sight being blocked by a front end valve.

By this time in the project a second laser tracker had been purchased so it was decided to utilise this instrument for the alignment. The main challenge was stationing the instrument in a position where it could see the survey monuments, figure 19. The front end is positioned between the storage ring and ratchet wall linking the ring to the beamline, this area is necessarily tight for space. The SR girder survey monuments were designed to receive a force-centred theodolite but this interface was not compatible with the laser tracker.

Figure 19: Front end alignment with laser tracker

Mounting the instrument on a storage ring girder was the optimum position therefore a magnetic base was specified and procured for this purpose. The alignment process proved very quick using the laser tracker combined with a bubble level controlling the roll of the assembly.

4. BEAMLINE ALIGNMENT

Initial work on the beamlines commenced prior to completion of the storage ring girder installation. As the storage ring would ultimately become the datum for aligning the beamlines, an interim alignment was required to allow beamline construction to start.

During the building construction phase, reference pins and target nests had been installed within the experimental hall floor. These were measured as a network whilst the experimental hall was clear of obstructions and provided the initial control for setting out and building the beamline hutches (shielded enclosures housing the beamlines).

When casting the storage ring ratchet wall, survey ports had been fitted co-linear with the nominal beam centreline for each beamline. These ports would allow the transfer of each beamline datum directly through the wall into the hutch from the storage ring. As hutches became available, alignment frames where positioned at either end of the hutch and laterally adjusted onto the beamline reference line as defined by a theodolite in the storage ring. At this stage the reference line was defined with respect to the SR ring construction network, if necessary the frames could be further adjusted once the SR girder positions were finally defined.

In the majority of cases, beamline components were supplied with survey monuments at each end at a predefined height above the nominal beam centre. This classical approach provided maximum flexibility with respect to instrument selection for the alignment task. Theodolites and levels could be combined to align a component or a laser tracker could be utilised within a 3D network or booked into a gravity system as described for the booster installation.

Access permitting, the laser tracker was the preferred instrument for the majority of beamline alignment tasks, figure 20. It does not have to be set up on beam axis to optimise accuracy as per a theodolite and its dynamic measurement properties provide real time measurement for the technician carrying out the alignment task. The need for multiple operatives is removed resulting in a very efficient process.

Where survey monuments have not been provided, the laser tracker SA software can manipulate measured data to define alternative features such as flanges, planes holes etc to facilitate an alignment.

Figure 20: Beamline alignment with laser tracker

Co-ordinate frames can be quickly generated and transformed to meet the requirements of the task and all of this can be carried out at the workplace.

5. CONCLUSION

The survey networks, installed and measured prior to machine installation, have achieved the design parameters for uncertainty and functionality. By providing a combination of force-centred instrument mounts and floor/wall mounted target nests, a high degree of flexibility was available for instrument selection.

The decision to use TDA 5005 total stations for the measurement of the storage ring construction network and subsequent girder surveys has proven successful both in terms of the results obtained and the time efficiency of the process. Utilising automatic target recognition and axis motor drives on the instrument together with a dedicated software interface has proven extremely effective.

Diamond’s Faro laser trackers combined with Spatial Analyzer software have provided an adaptable, portable 3D measurement system that has been regularly applied to a variety of tasks, both planned and unforeseen. SA has also been utilised with Total Station theodolites and a Faro Arm running the same software has recently been added to the survey group’s toolbox.

To close the loop, a digital level interface combined with level data integration within SA's USMN is desirable. This would allow a 3D network adjustment from a combination of total station angles and distance combined with elevations derived from digital level data. Diamond is currently working with SA's software developer New River Kinematics (NRK) in pursuance of this goal.

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References

[1] C. Christou et al, “Commissioning of the Diamond Pre-injector Linac”, EPAC 06, Edinburgh

[2] V.C. Kempson et al., “Commissioning of the Booster Synchrotron for the Diamond Light Source”, EPAC 06, Edinburgh

[3] R.P. Walker, “Overview of the Status of the Diamond Project”, EPAC 06, Edinburgh

[4] D.W. Wilson “Survey and Alignment for the Diamond Light Source”, IWAA 2004, CERN, Geneva.

[5] N. Hammond, “Storage Ring, Mechanical Engineering Design”, Proc. MEDSI 2002, Argonne

[6] N Levet, D Martin, Optimisation of the ESRF storage ring level survey and network, IWAA 2002, Spring-8

[7] S. Zelenika et al, “Mechanical Design of the SLS Storage Ring”, Proc. MEDSI 2000, Villigen, p.36

[8] G. Bowden et al, NIM A368 (1996) 579

[9] A. Streun, “Algorithms for Dynamic Alignment of the SLS Storage Ring Girders”, SLS-TME-TA-2000-0152, June 2000

[10] I. Martin et al., “Diamond Storage Ring Remote Alignment System”, EPAC 06, Edinburgh